Geospatial Technology for Landslide Hazard Zonation Based on Rainfall Rate by Using Remote Sensing Data in Dharamshala Region, Nw Himalayas H.P

Shilpa Dhiman[1*] and Pooja Rajput[2]

[1]OPJS University, Churu, Rajasthan
[2]Deptt. Of Geology, Govt. P.G. College, Dharamshala (H.P)

[*]**Corresponding author's email:** shilpadhiman06@gmail.com

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ABSTRACT

Landslides are very common Geo-hazards in the mountainous regions. Rain during the monsoon season further aggravates this phenomenon. The present study of rain-induced landslides in the Dharamshala region has been carried out to show the relationship between rainfall precipitation and landslides. The precipitation data was collected from the Centre for Hydrometeorology and Remote Sensing – CHRS Data Portal and analyzed for annual and season wise variations for a period of 10 years from 2011-2020. The data was interpreted through spatial distribution methods in GIS and correlated with existing landslide locations. The total study area is 105.46 sq.km and various Isohyetal maps of different seasons were prepared. Landslide locations are superimposed to monsoon isohyetal maps. The maps clearly showed that the occurrence of landslides depends upon intensity of rainfall; if intensity of rainfall changes the occurrence of landslides changes. The result reveal that high intensity rainfall attributed to North-West of study area of study area and hence Ghera, Dharamshala and Khaniara region suffered to severe landsliding events while the rainfall intensity decreases towards South – East of study area i.e. towards Narwana and Kand and so as the occurrence of landsliding events. Thus, the study clearly revealed that landslide events directly depend upon intensity of rainfall. Higher the intensity of rainfall more will be chances of slope failure and if there is any change in intensity of rainfall, the occurrence of landslide events will also be changed. This paper highlights the application of GIS in spatially locating the relation between rainfall and landslides.

Keywords: *Landslides, CHRS, Geospatial distribution, Isohyetal maps, Rainfall and GIS.*

INTRODUCTION

The term "Landslide" is often used to refer to all types of slope movements whether they involve true sliding or not. Landslides are widespread, frequent and sudden geohazards especially in mountainous terrain that strike human lives, livestock, livelihood, habitats and environment in an adverse manner resulting in huge losses and damages directly or indirectly. Landslides are defined as the mass movement of rocks, debris or earth along a sliding plane. They are characterised by almost permanent contact between the moving masses and sliding plane (Butler, 1976; Crozier,1984; and Smith, 1996).

Landslide studies have been getting global intentions now-a-days not only because of increasing awareness of socio-economic harmful impacts but also increasing pressure of urbanisation on the mountain regions. Now-a-days, because of increased unplanned urbanisation, increased regional precipitation due to climate changes, and continued deforestation in landslide prone regions, landslide problems seem to be more challenging in the future.

Landslides are usually associated with prolonged periods of heavy rainfall. Rainfall is not the sole criteria for occurrence of landslides but also the geological or soil properties are equally important. Detailed study on rainfall-induced Landslides are carried out in the Indian Himalayan region (Dikshit, 2020). Geospatial Technology Based Rainfall Precipitation Assessment with Landslides in Mettupalayam – Aruvankadu Highway, Tamil Nadu (Ganesh, R 2017) showed that landslides directly depend upon the intensity of rainfall.

Number of studies have attempted to correlate rainfall events and the slope failure by many authors in different countries such as Vargas (1971), Guidicini and Iwasa (1977), Caine (1980), Crozier and Eyles (1980), Vaughan (1985), Senanayaka *et al.* (1994), Finlay *et al.* (1997) and Guzzetti et al. (2007). The significant role of rainfall and soil properties has been indicated by Brand et al. (1984), by their study on typical characteristics of slope failures in Hong Kong, and Rahardjo et al. (2007), based on investigations of slope failures in Singapore.

The studies clearly reveal that the shallow slope failure mechanism is triggered by infiltration of rainwater to surficial soils (Fourie, 1996). This infiltration reduces the shear strength of soil and ultimately it causes failure to various scales depending upon other controlling factors.

STUDY AREA

The study area lies on steep slopes of Outer Himalayan Terrain falling within $32^0$14’2.710'' N to $32^0$10’26.000” N latitudes and $76^0$16’43.353” E to $76^0$24’52.000” E longitudes covering an area of 105.46 Km^2(Fig.1). The study area is covered by Survey of India Toposheet no.52D/8 under scale 1: 50,000. The study area includes the parts of Ghera village, Dhramshala city, Mcleodganj, Bhagsu Naag, Chola, Khaniara, Kharota, Lungta, Rakkar,Kasaba Narwana,Salig and Kand village. The area is dissected by number of streams locally known as khads namely Gaj khad, Banoi Khad, Churan Khad, Sauli Khad, Manjhi Khad, Manuni Khad, Nod Khad and Iku Khad and their small tributaries locally known as nalas. Thus, the western end of the study area is marked by stream Gaj while the Eastern end is marked by stream Iku. Dharamshala is credited as being the third highest wettest place, after Mawsynram and Cherrapunji. It experiences average annual rainfall of about **3000mm** (Meteorological Centre, Shimla). Moreover, the physiography and geotectonics of the area indicates that the area is highly fragile and active hence associated with natural disasters like earthquakes (zone V) and landslides (Disaster Management Authority of India).

GEOLOGICAL SETTING

The area is covered by Dhauladhar Granitoids mainly comprising of Granites, Chails Group rocks comprising of Gneisses, schists, phyllites, slates and schistose quartzites, Dharamsala Traps, Subathu formation comprising of purple shale and sandstone, Dharamkot limestone and dolomites, a thick succession of lower, middle and upper Siwalik sediments which comprises mainly the sandstone, clays and boulder conglomerates which are succeeded by recent alluvium towards the south (Fig.2).

Most of the study area consists of Dharamshala formation. The strata are composed of soils or clays which are highly susceptible to infiltration and oversaturation during heavy and prolonged rainfall. The continuous infiltration reduces matric suction until the shear strength of strata is no longer sufficient to maintain the stability and finally slope failure occurs.

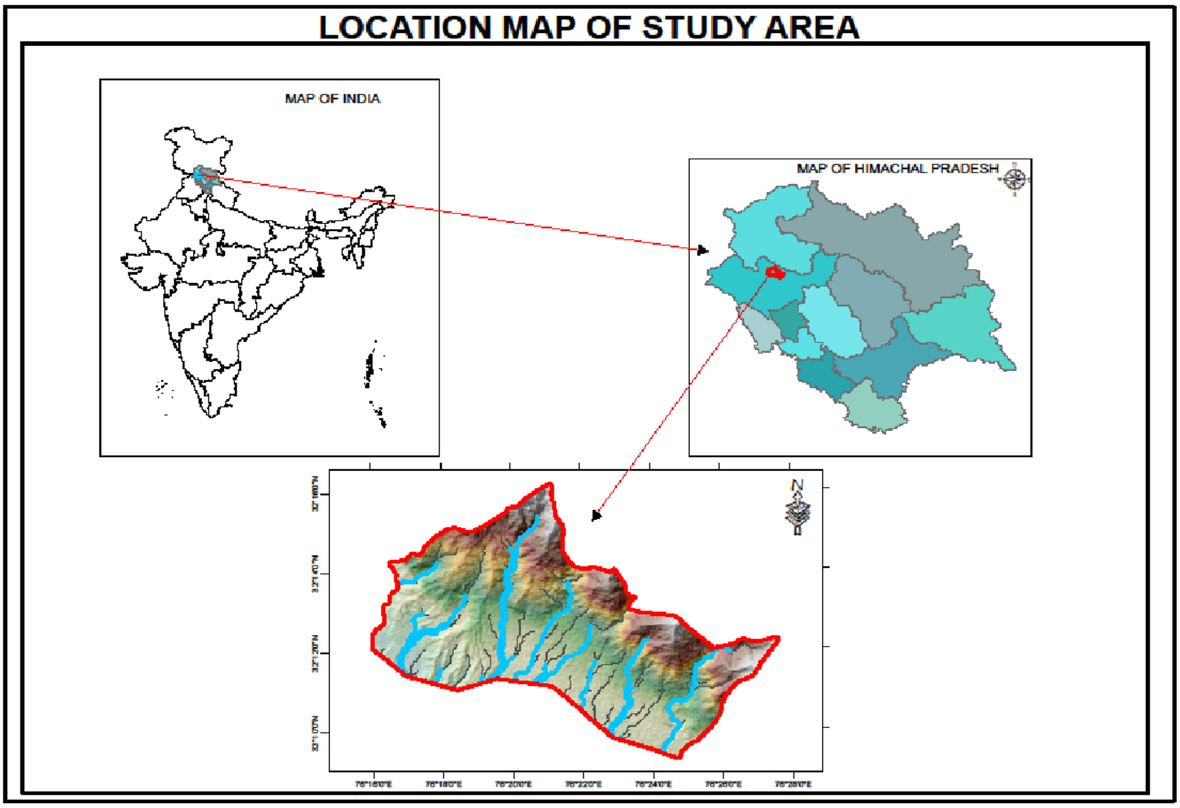


Fig.1. Location map of study area

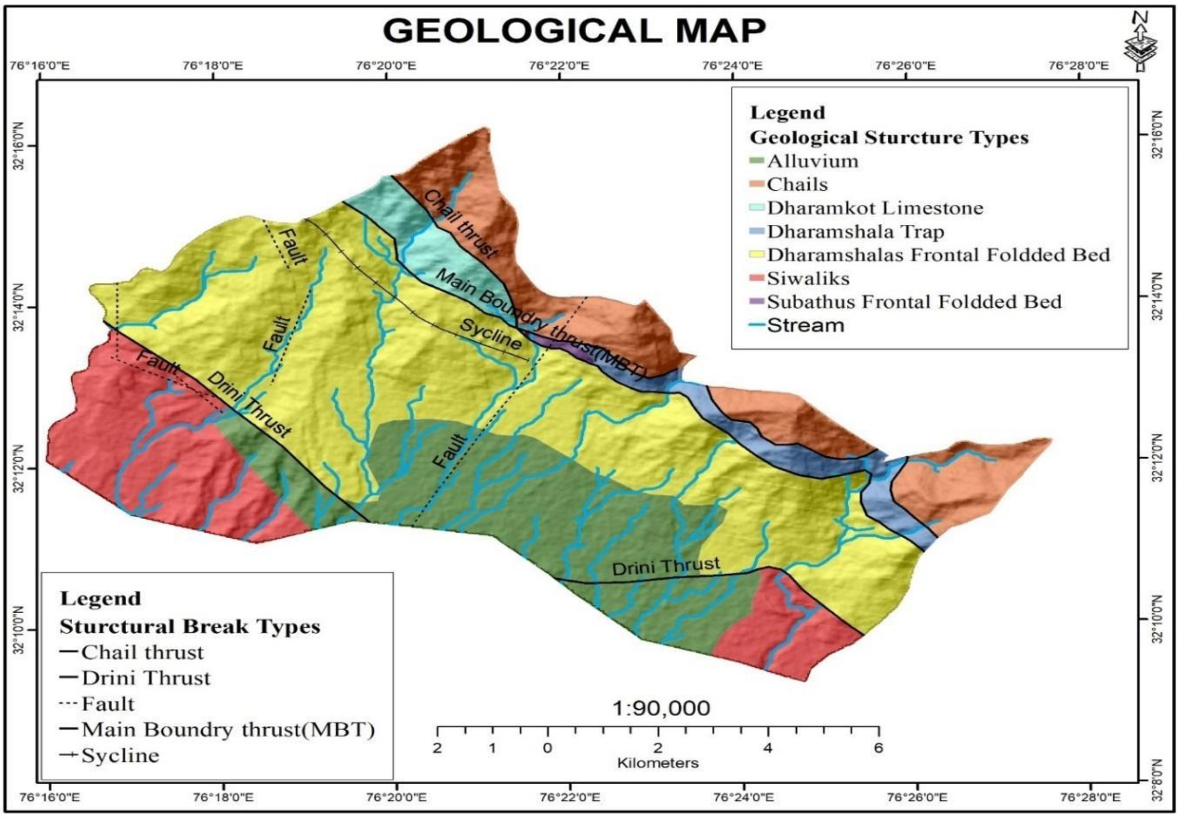


Fig.2. Geological Map of Study area

METHODOLOGY

The maps are prepared using Arcgis software at a scale of 1:90,000. In the present study, the average annual rainfall data of a period of 10 years (2011-2020) have been collected from CHRS Data Portal for ten stations in study area (Table 2) and the graph and Isohyetal map prepared from the same at a resolution of 30m. Further the data for year 2011, 2015 and 2020 have been split into season wise Pre-monsoon season (March-April), Monsoon season (June-September) and Post-Monsoon season (October-November) for the preparation of variation diagrams. The spatial variability of mean annual precipitation depends upon the topographic factors such as exposure of the station to the prevailing wind, elevation, orientation and slope of the mountain (Basist A and Bell G.D.,1994). Landslide inventory has been prepared by field surveys and demarcated the GPS locations of major landslides encountered in the field between April 2020 to September 2021. 42 landslides studied in study area of varying size and different types most of which are activated during monsoon season; usually in the form of Debris flow, mudslide or Earth flow (Table 7). Finally, landslide location map prepared by superimposing these locations monsoon Isohyetal map (fig. 8).

Arithmetic mean method is used for calculation of average rainfall at all ten stations. The rainfall amount at all the ten stations summed up and the total divided by the number of years/months. Arithmetic method is the simplest objective method of calculating the average rainfall over the area (Basavarajappa *et al.,* 2015a).

The Isohyetal method is used to estimate the mean precipitation across an area by drawing lines of equal precipitation (isohyets) on a map. It is one of the most convenient methods that views continuous spatial variation of rainfall in a given area.

RESULT AND DISCUSSION:

The result of Pre-Monsoon, Monsoon, Post-Monsoon and average annual rainfall data for 2010-2020 were used for preparation of spatial distribution isohyetal maps using geospatial technology. The data are given in tables 1 to 5 and the resultant graphs (1- 4) and maps are shown by figures 3 to 6.

Average Annual Rainfall (2010-2020)

Over the period of 11 years from 2010-2020, Dharamkot area received highest average rainfall of 1276.91mm while Ghera area received lowest average rainfall of 1182.09 mm. The study area received the lowest rainfall in 2011 while it received the highest rainfall in 2018. In 2015 the area had average rainfall but highest in the last 5 years. The Isohyet map shows an increasing intensity of rainfall towards higher altitudes of the study area.

Pre- Monsoon season (March-May)

During the pre-monsoon season, the study area recorded an average rainfall of 345.18 cm. The highest average rainfall of 109.34cm was recorded in Rising Star Hill top station nearby Khaniara region while the lowest average rainfall of 94.22 cm was recorded in Sakoh nearby Dharamshala city.

Monsoon Season (June- September)

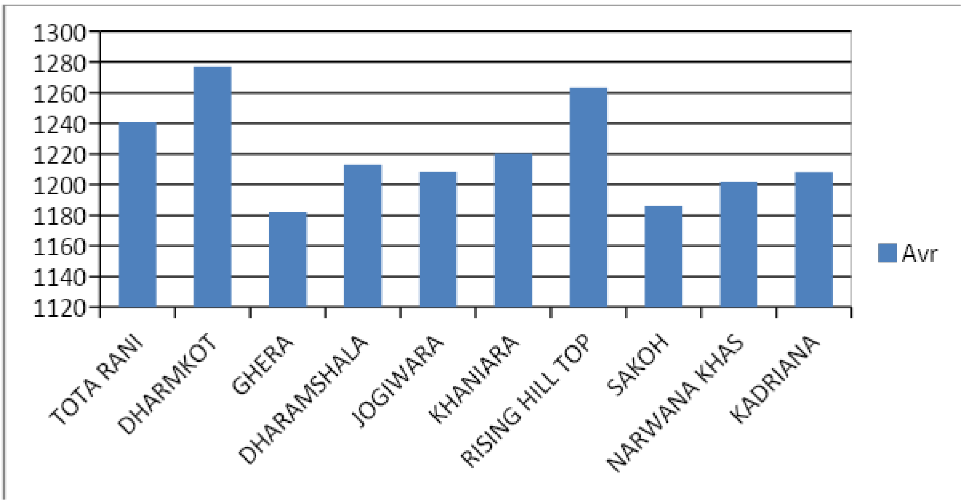
During the monsoon season the study area recorded an average rainfall of 494.26 cm. The highest average rainfall 168.41 cm was recorded from Dharamshala station while the lowest average rainfall i.e 135.66 cm was recorded from Kardiana station.

Post-Monsoon (October- November) This season contributes least towards the rainfall. During this season the study area recorded an average rainfall of 20.38cm. The highest average rainfall 22.66cm recorded from Total Rani station lies at high altitude and on a steep slope while the lowest average rainfall 17.83 cm again recorded from Sakoh station. It is observed from figures 4, 5 and 6 that Isohyetal maps of pre- monsoon are lesser than Monsoon. In this map the increasing order of intensity of rainfall is noticed towards the North which is covered by steep slopes of high altitude. (Fig.4). However, the Monsoon Isohyetal map shows that the scenario is quite high as compared to the other two seasons. In this map the intensity of rainfall is highest at western side of the study area and a decreasing order of intensity is noticed as we move towards east. (Fig.5). Although the contribution of Post – Monsoon rainfall is too low in study area still an increasing order of rainfall is noticed towards eastern side (Fig.6)

Table 1. Annual average rainfall at ten stations (2010-2020 in mm)

LOCATION	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Avr
TOTA RANI	1090	902	1431	1162	1101	1447	899	1351	1813	1307	1148	1241.00
DHARMKOT	1177	892	1508	1278	1164	1373	965	1307	1890	1360	1132	1276.91
GHERA	1090	889	1352	1096	1039	1326	804	1296	1779	1179	1153	1182.09
DHARAMSHALA	1093	844	1374	1177	1109	1412	799	1342	1720	1242	1230	1212.91
JOGIWARA	1138	792	1385	1157	1092	1375	892	1199	1737	1330	1196	1208.45
KHANIARA	1160	816	1354	1164	1100	1409	923	1286	1771	1312	1131	1220.55
RISING HILL TOP	1233	860	1418	1281	1194	1324	980	1323	1916	1252	1115	1263.27

SAKOH	1126	821	1283	1240	1045	1215	834	1339	1727	1268	1152	1186.36
NARWANA KHAS	1135	828	1453	1169	1166	1219	916	1246	1717	1240	1133	1202.00
KADRIANA	1162	822	1373	1111	1172	1244	914	1269	1854	1302	1065	1208.00



Graph 1. Showing annual average rainfall for year 2010-2020 (in mm)

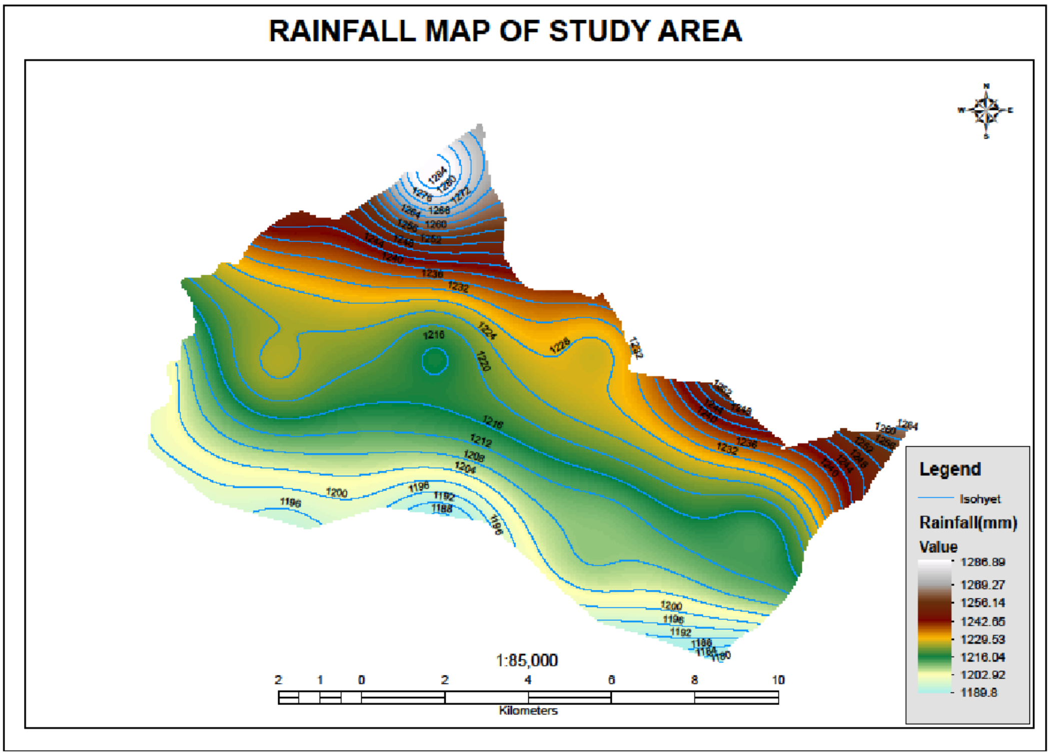


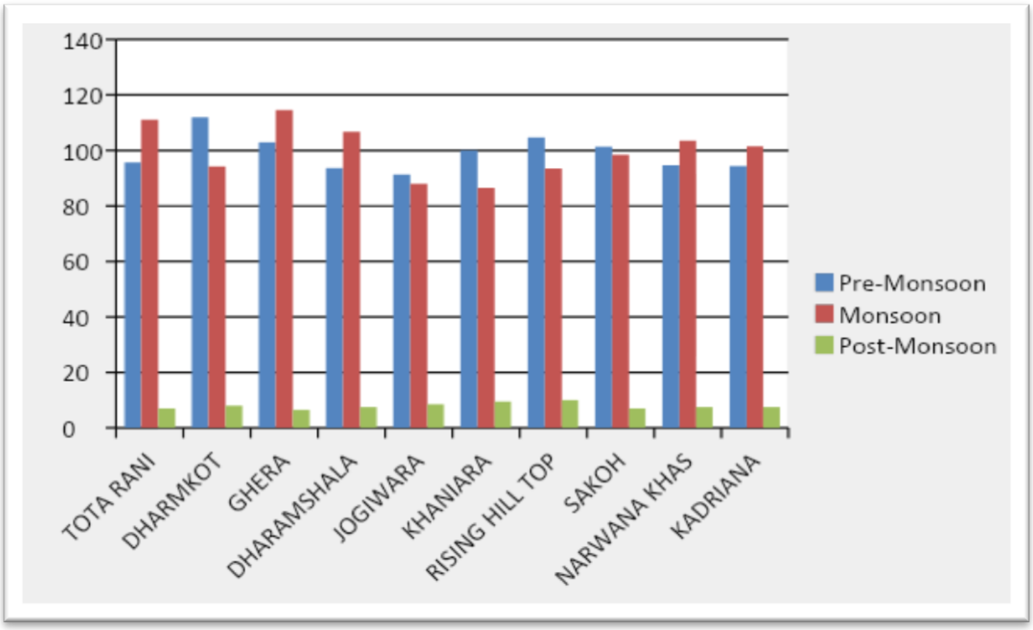
Fig. 3. Isohyetal map showing average annual rainfall (2010-2020 in mm)

Table 2a. Rainfall data of Pre- monsoon, Monsoon and Post- monsoon for year 2011 (in cm)

Location	March	APRIL	May	June	July	August	Sept.	Oct.	Nov.
TOTA RANI	27	136	124	44	69	228	103	8	6
DHARMKOT	35	160	141	36	90	174	77	7	9
GHERA	22	166	121	50	88	226	94	7	6
DHARAMSHALA	23	137	121	44	69	226	88	9	6
JOGIWARA	29	127	118	45	64	162	81	9	8
KHANIARA	32	148	120	47	68	150	81	10	9
RISING HILL TOP	34	163	117	43	74	163	94	11	9
SAKOH	24	166	114	58	106	138	92	6	8
NARWANA KHAS	29	141	114	86	92	155	81	9	6
KADRIANA	43	131	109	84	94	146	82	9	6

Table 2b. Average rainfall per season in year 2011 (in cm)

Location	Pre-Monsoon	Monsoon	Post- Monsoon
TOTA RANI	95.67	111.00	7
DHARMKOT	112.00	94.25	8
GHERA	103.00	114.5	6.5
DHARAMSHALA	93.67	106.75	7.5
JOGIWARA	91.33	88.00	8.5
KHANIARA	100.00	86.5	9.5
RISING HILL TOP	104.67	93.5	10
SAKOH	101.33	98.5	7
NARWANA KHAS	94.67	103.5	7.5
KADRIANA	94.33	101.5	7.5



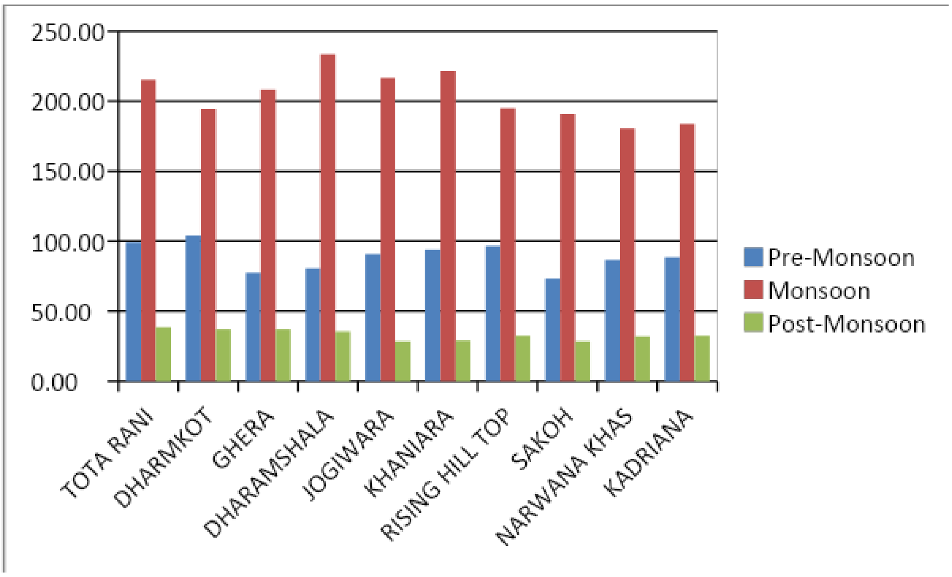
Graph 2. Average rainfall for three seasons at different stations 2011 (in cm)

Table 3a. Rainfall data of Pre- monsoon, Monsoon and Post- monsoon for year 2015 (in cm)

LOCATION	March	APRIL	May	June	July	August	Sept.	Oct.	Nov.
TOTA RANI	120	146	31	69	346	417	29	38	39
DHARMKOT	142	144	26	43	311	391	33	30	44
GHERA	102	108	22	64	360	385	24	37	37
DHARAMSHALA	101	122	19	64	441	403	26	34	37
JOGIWARA	122	132	18	46	424	372	25	30	27
KHANIARA	124	139	19	44	407	409	26	30	28
RISING HILL TOP	125	142	23	59	292	396	33	30	35
SAKOH	100	103	17	41	322	371	30	28	29
NARWANA KHAS	110	129	21	34	309	351	28	28	36
KADRIANA	111	134	21	61	300	348	27	27	38

Table 3b. Average rainfall per season 2015 (in cm)

Location	Pre-Monsoon	Monsoon	Post- Monsoon
TOTA RANI	99.00	215.25	38.50
DHARMKOT	104.00	194.50	37.00
GHERA	77.33	208.25	37.00
DHARAMSHALA	80.67	233.50	35.50
JOGIWARA	90.67	216.75	28.50
KHANIARA	94.00	221.50	29.00
RISING HILL TOP	96.67	195.00	32.50
SAKOH	73.33	191.00	28.50
NARWANA KHAS	86.67	180.50	32.00
KADRIANA	88.67	184.00	32.50



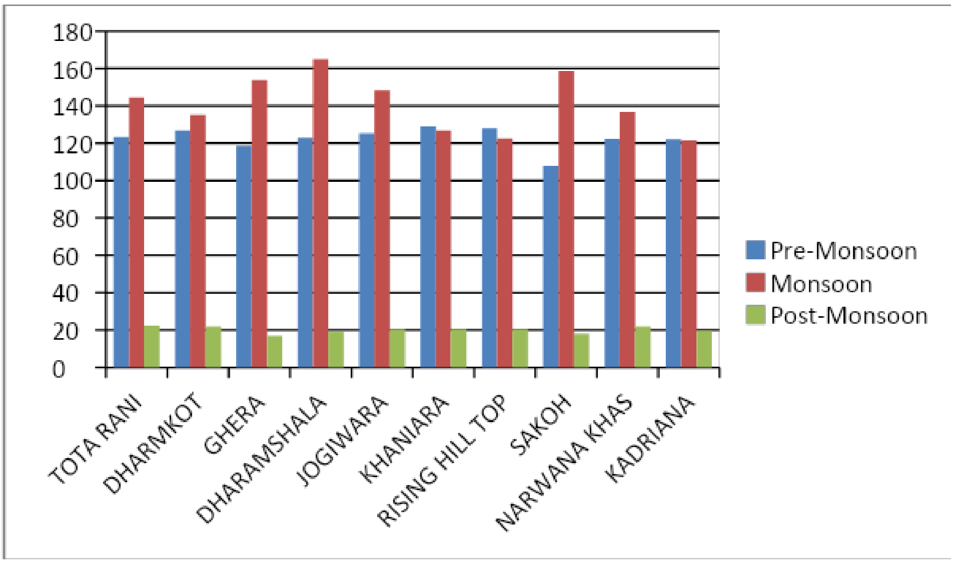
Graph 3. Average rainfall for three seasons at different stations 2015 (in cm)

Table 4a. Rainfall data of Pre- monsoon, Monsoon and Post- monsoon for year 2020 (in cm)

Location	March	APRIL	May	June	July	August	Sept.	Oct.	Nov.
TOTA RANI	187	88	95	27	150	348	53	0	45
DHARMKOT	187	89	104	27	136	326	52	0	44
GHERA	175	106	75	34	186	363	32	0	34
DHARAMSHALA	182	109	78	35	234	364	27	0	38
JOGIWARA	173	119	84	40	182	343	28	0	41
KHANIARA	183	116	88	43	137	299	28	0	41
RISING HILL TOP	177	113	94	41	149	273	27	0	41
SAKOH	177	84	63	74	208	308	45	0	36
NARWANA KHAS	189	98	80	45	170	298	34	0	44
KADRIANA	174	93	99	46	131	274	35	0	39

Table 4b. Average rainfall per season 2020 (in cm)

Location	Pre-Monsoon	Monsoon	Post- Monsoon
TOTA RANI	123.33	144.50	22.50
DHARMKOT	126.67	135.25	22.00
GHERA	118.67	153.75	17.00
DHARAMSHALA	123.00	165.00	19.00
JOGIWARA	125.33	148.25	20.50
KHANIARA	129.00	126.75	20.50
RISING HILL TOP	128.00	122.50	20.50
SAKOH	108.00	158.75	18.00
NARWANA KHAS	122.33	136.75	22.00
KADRIANA	122.00	121.50	19.50



Graph 4. Average rainfall for three seasons at different stations 2020 (in cm)

Table 5. Average Rainfall per Season 2011-2020 (in cm)

LOCATIONS	PRE-MONSOON SEASON	MONSOON SEASON	POST-MONSOON SEASON
TOTA RANI	106.00	156.91	22.66
DHARMKOT	114.22	141.33	22.33
GHERA	99.67	158.83	20.16
DHARAMSHALA	99.11	168.41	20.66
JOGIWARA	102.44	151.00	19.16
KHANIARA	107.66	144.91	19.66
RISING HILL TOP	109.34	137.00	21.00
SAKOH	94.22	149.41	17.83
NARWANA KHAS	101.22	140.25	20.50
KADRIANA	101.66	135.66	19.83
AVERAGE	**345.18**	**494.26**	**20.38**

ISOHYETAL MAP

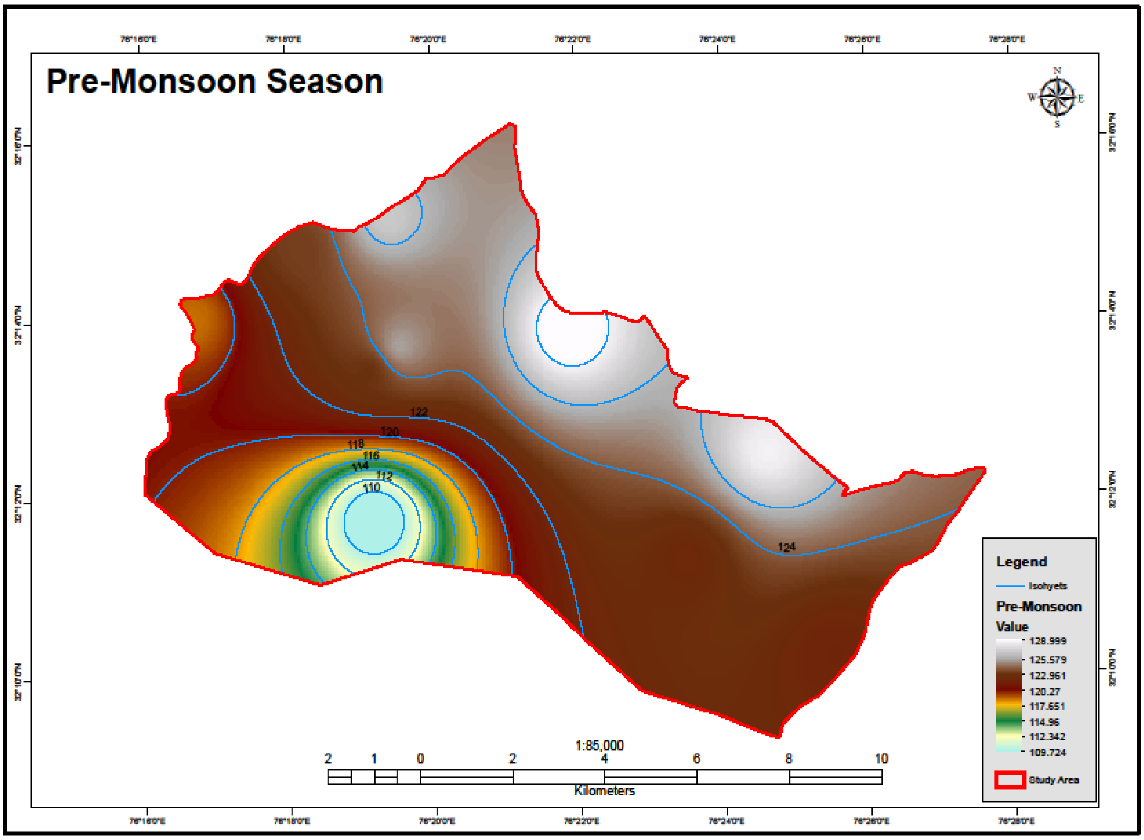


Fig. 4. Isohyetal Map of Pre-Monsoon

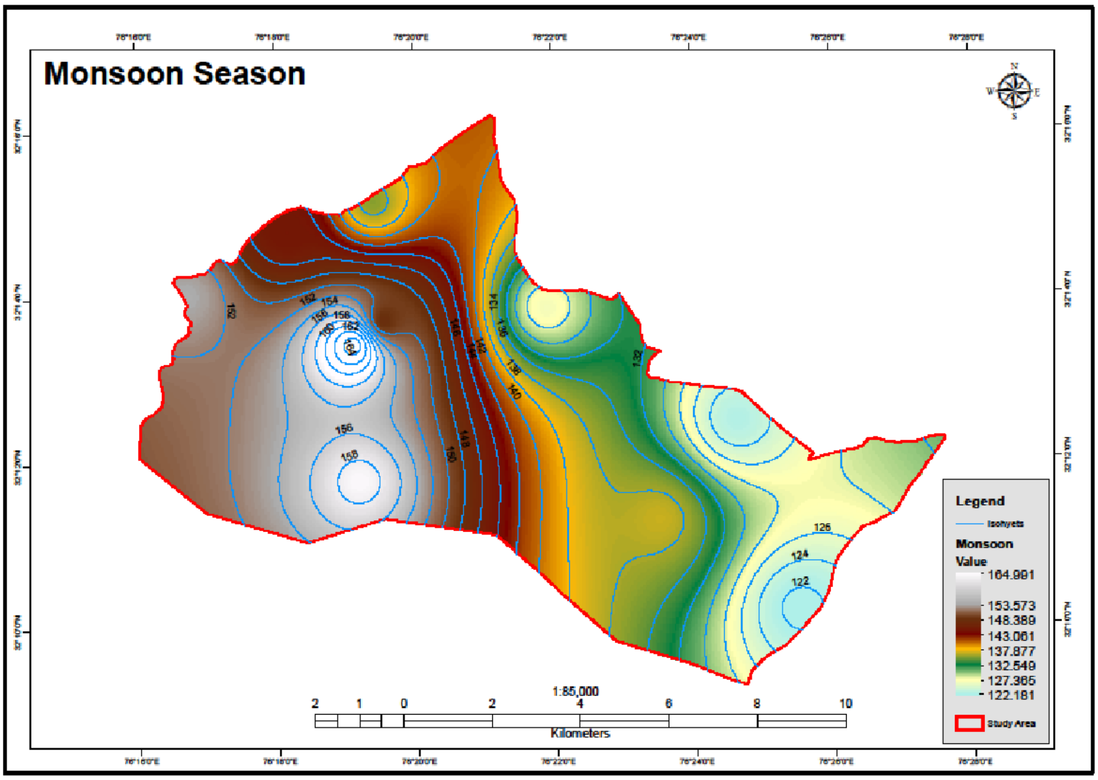


Fig.5. Isohyetal Map of Monsoon season

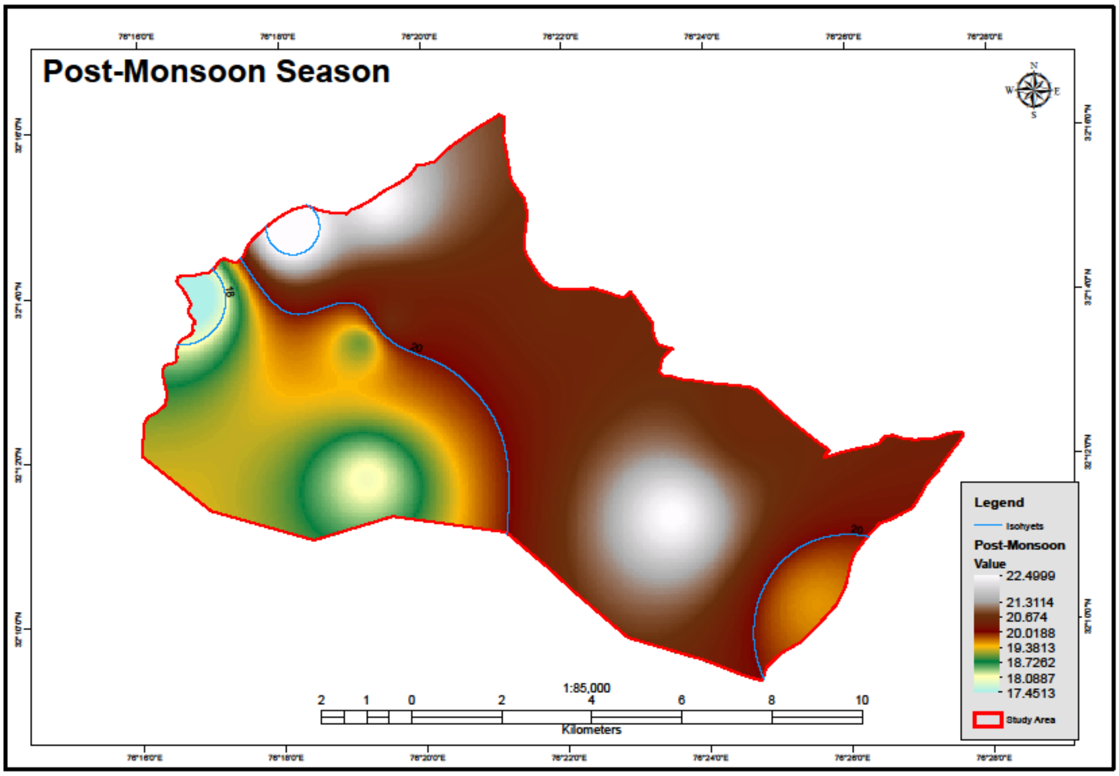


Fig.6. Isohyetal Map of Post Monsoon season

Rainfall and Landslides

The rainfall is considered as one of the most important and triggering factors to the landslides because water alters the pressure within the slope, which leads to slope instability. Consequently, the heavy water – laden slope material will succumb to the force of gravity and start moving down to the slope at different rates. Mostly the landslides occurring in this region are triggered by rainfall followed by other factors like steep slopes, weak lithology, thrust and drainage system. The area suffers from lots of sliding activities especially during the rainy season. One of the major landslides studies in the study area shown in figures 7.

By field studies of landslides, duration of occurrence of landslides and amount & period of rainfall; it is clear that rainfall triggers landslides. Also, by superimposing landslide locations on Isohyet Map (Fig.8) it is clear that areas receiving high amount of rainfall i.e., Dharamshala, Tirah line, Mecleodganj, Jogiwara, Bhagsu Naag etc. are suffered with severe landsliding. Areas with moderate intensity of rainfall ie kharota, Lungta, Khaniara,Thathari, Rakkad etc. have lesser slides but cause severe debris flow due to illegal slate mining and improperly dumping of debris on steep slopes. Further the amount of rainfall is least towards Tikkri, Kand and Kardiana village and so as the scenario of landsliding in the area. Major slides occur where the lithology and other factors favours landsliding.

Fig.7. Buildings collapse due to severe landslide at Tirah line

Table 7. Landslide inventory of study area

Sr. No.	Landslide area	Latitude	Longitude
1	Gaj Project	32°14’2.710”N	76°16’43.353”E
2	Diara	32°13’41.000”N	76°16’50.000”E
3	Ghera road 1	32°13’13.080”N	76°16’40.800”E
4	Ghera road 2	32°13’14.656”N	76°16’40.667”E
5	Kotwali Taxi stand	32°13’8.000”N	76°19’3.000”E
6	Cantt. By-pass road	32°13’30.000”N	76°19’4.000”E
7	Cantt. Road Kotwali	32°13’21.000”N	76°19’5.000”E
8	Kala pull	32°13’58.816”N	76°19’8.751”E
9	Tirah line	32°13’45.198”N	76°18’15.948”E
10	Forsyth Ganj	32°14’32.770”N	76°19’0.209”E
11	Mcleodganj	32°14’24.500”N	76°19’25.663”E
12	Gallu devi	32°15’9.789”N	76°19’24.982”E
13	Bhagsu	32°14’44.343”N	76°20’14.834”E
14	Khara Danda road	32°13’58.256”N	76°19’36.590”E
15	Mcleodganj bypass	32°13’25.000”N	76°19’0.000”E
16	International cricket stadium Dharamshala	32°12’0.230”N	76°19’30.364”E
17	Upper Sakoh	32°13’25.000”N	76°19’0.000”E
18	Near Dal lake	32°14’35.432”N	76°18’45.414”E
19	Tota Rani	32°14’48.233”N	76°18’9.782”E
20	Near Buddhist Stupa	32°13’49.000”N	76°19’23.000”E
21	DC residence	32°13’25.687”N	76°19’6.669”E
22	Jogiwara	32°13’43.774”N	76°19’34.044”E
23	Ramnagar bridge	32°13’15.950”N	76°19’47.420”E
24	Indru Nag	32°13’7.071”N	76°20’18.713”E
25	Chola	32°13’43.000”N	76°20’10.000”E
26	Juhl	32°13’24.971”N	76°21’32.920”E
27	Batkolu temple	32°13’52.000”N	76°21’54.000”E
28	Kharota	32°12’45.909”N	76°22’53.861”E
29	Lungta	32°12’38.186”N	76°22’57.457”E
30	Khaniara	32°13’13.731”N	76°21’54.301”E
31	Thathari Hydro Project	32°13’51.196”N	76°22’3.041”E
32	Thathari	32°13’59.517”N	76°21’37.820”E
33	Near old Phalku temple	32°12’15.666”N	76°22’54.227”E
34	Rising Hill top	32°12’29.412”N	76°24’37.759”E
35	Rakkar Helipad	32°11’45.000”N	76°22’45.000”E
36	Near Naudraani temple	32°11’34.000”N	76°23’21.000”E
37	Biodiversity Park	32°11’17.371”N	76°23’29.421”E
38	Khidku	32°11’6.000”N	76°24’1.000”E
39	Salig	32°11’12.000”N	76°24’15.000”E
40	Tikkri	32°10’48.714”N	76°24’29.419”E
41	Kand	32°10’26.000”N	76°24’52.000”E
42	Kadriana	32°10’11.384”N	76°24’31.538”E

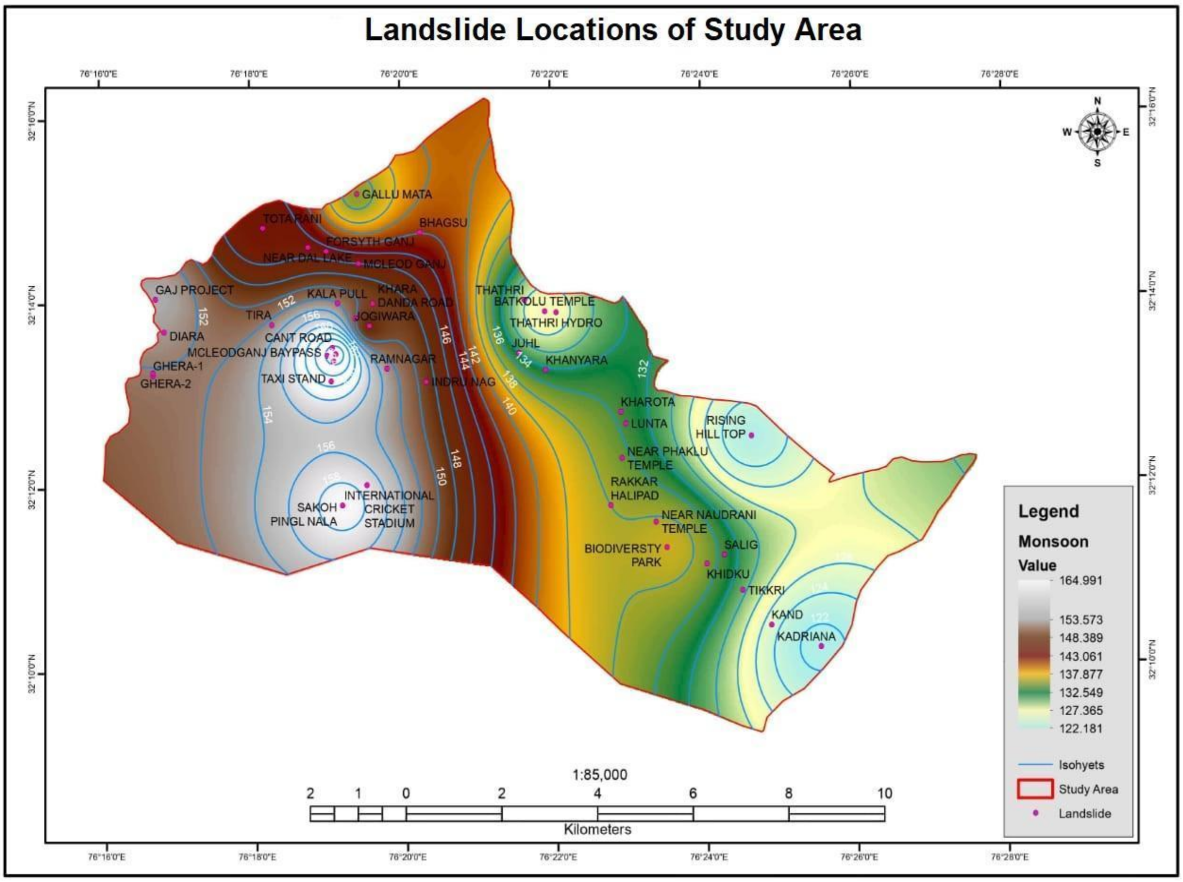


Fig.8. Monsoon Isohyetal Map showing Correlation of rainfall and landslides in study area

CONCLUSION

Seasonal analysis of rainfall concludes that the highest amount of rainfall is recorded during the Monsoon season in months of July and August, while the lowest intensity is recorded during the post-monsoon season in the study area. The result of the correlation of landslides and rainfall shows that the occurrence of landslides is directly caused by intensive rainfall. If there is a change in the amount of rainfall, it will lead to a change in the occurrence of landslides.

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